Evaluate Live Capture Selective Harvest Methods: 2002

Annual Report for BPA Contract 2001-007-00

Objective 1

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ABSTRACT

Selective fishing is the ability of a fishing operation to avoid non-target species or stocks, or when encountered, to capture and release them in a manner that minimizes mortality. The tangle net was tested on the lower Columbia River for the second year in 2002 to selectively harvest adult spring chinook salmon (*Oncorhynchus tschawytscha*). Experienced gill netters simultaneously fished tangle nets (4.5" mesh size) and 5.5" mesh nets on the Columbia River to evaluate their effectiveness for live release of non-target stocks of spring chinook salmon. Live fish were tagged and released for recovery in sport fisheries, commercial fisheries, at hatchery racks and traps, and during spawning ground surveys. Control fish that had not been captured in the test gears were tagged and released from an adult trap in Bonneville Dam, just upstream of the fishing area. The 4.5" tangle net caught significantly fewer spring chinook salmon than the 5.5" net. Fish were generally captured in good condition. The immediate survival (from capture to release from the boat) of adult spring chinook salmon captured in the 5.5" net was 99.1%, compared to 99.5% from the 4.5" tangle net. However, spring chinook salmon captured with the 4.5" tangle net survived significantly better post-release than spring chinook captured with the 5.5" net. Spring chinook salmon released from the tangle nets were recovered at about 68% of the rate of controls, while spring chinook salmon released from the conventional 5.5"net were recovered at about 57% of the rate of the controls. The results of the 2002 tests provided a replicate and another survival estimate for fish captured in a 4.5" tangle net using short soak times and careful fish handling techniques. The wide confidence intervals and different survival rate for the 4.5" tangle net between the 2001 and 2002 study years require this study continue so that a more precise survival value may be obtained. Despite the lower survival rate obtained for fish captured in the tangle net in 2002, the results still support that the post-release mortality on non-target stocks (e.g., wild spring chinook) can be reduced compared to the 5.5"or the conventional gill (8") nets. The 2002 results further indicate that the 5.5"net is intermediate to the conventional gill net and 4.5" tangle net and therefore that the 5.5" net does not act as a true gill net or a true tangle net for spring chinook salmon.

INTRODUCTION

The Columbia River is one of the largest chinook salmon (*Oncorhynchus tshawytscha*) producing rivers in the world. However, like many other rivers in the Pacific Northwest, it has not been spared from declines in salmon populations; several stocks of spring, summer and fall chinook salmon are listed as threatened or endangered under the federal Endangered Species Act. Of all the Columbia River salmon, the flesh quality and high fat content make the spring chinook salmon the most prized. From 1977 until 2000, there were no mainstem non-treaty commercial fisheries for upriver spring chinook because of small run sizes. The process of reopening this fishery began in 2001 with the largest return of spring chinook salmon to the Columbia River since the Bonneville Dam began operation (1938). Because weak stocks of spring chinook salmon returning to the Columbia River are intermingled with healthy stocks returning to hatcheries and spawning sites, traditional commercial harvest methods in these mixed stocks fisheries are a problem. Fishers using gill nets inadvertently catch weaker species and stocks while targeting salmon from stronger runs. Because of the capture method of gill nets, successful live release from them is difficult. The only practical way gill net gears can be more selective is by time and area closures. While these restrictions can be very efficient at reducing by-catch and meeting the conservation goal for the fishery, they necessarily reduce fishing opportunity for the target species and do not meet the harvest goals.

Selective harvest methods include uses of technologies and practices that allow a continued harvest, while protecting weak stocks. "Selective fishing," more accurately described as “live capture, selective harvest,” is the ability of a fishing operation to avoid non-target species or stocks, or when encountered, to release those animals in a manner that results in minimal mortality. Successful selective fishing requires that two objectives be met. First, a conservation goal must be achieved for the species or stock of concern, and second, a harvest goal must be met to make the fishery economically viable. In 2001 we began working with the commercial fishing industry to develop acceptable live capture gears that will provide more fishing opportunity while continuing to protect weak stocks. Key to a successful mixed stock selective fishery is the ability to distinguish the target and non-target fish from one another. Simultaneous with the development of selective fishing methods, large portions of the hatchery production of spring chinook salmon are being identified by the excision of the adipose fin before release as juveniles. When these fish return as adults, fishers can distinguish them from naturally produced fish that do not have an excised adipose fin.

The tangle net shows great promise as a commercially viable substitute for gill nets and seems to meet the criteria for selective fishing. Tangle nets look similar to a gill net with a small mesh size (typically 3.5”-4.5”). Tangle nets are made from multifilament web while gill nets are typically made from monofilament web. Both gears are fished in the same manner and locations, but the similarities stop there. Unlike a gill net, which captures an adult salmon around the gills or body, the mesh size of the tangle net prevents adult fish from entering the net that far. Instead, the fish is caught by the maxillary or teeth, which allow it to continue respiring in the net, so it can be released live. External and associated internal injuries are also reduced using this capture method. Modifications in fishing practices, including the use of fish recovery boxes, short soak times, and careful fish handling, are as important as the gear in ensuring that fish are released live and unharmed.

The premise of live capture, selective harvest is that it is possible to release fish in good condition and that they will survive to contribute to rebuilding their stock. Certainly, it has been shown that immediate and delayed mortality caused by encounters with commercial gear can be high (see review by Chopin and Arimoto, 1995). However, we are not aware of any published studies looking at the long-term survival of fish that have been captured and released from commercial gill nets to freely swim. Further, we are not aware of any published studies that compare immediate and delayed survival of fish captured in gill nets, which typically gill or wedge the targeted species, with tangle nets, which may be a more benign capture method since they typically capture targeted species by the teeth or mouth. The survival of fish captured and released in sport fisheries has been shown to vary considerably, and likely depends on the species captured, the skill of the fisher in releasing the fish, the water temperature, and the fishing method (Bendock and Alexandersdottir 1993; Gjernes et al. 1993; and see Muoneke and Childress 1994 for a review). Because most commercial fisheries, particularly those using gill nets, are managed to harvest the captured fish, few studies have evaluated the long-term effects of capture and release from commercial fishing gears. Candy et al. (1996) used ultrasonic telemetry to estimate that about 77% of chinook salmon (O. *tshawytscha*) captured in and released from seine nets survived. However, these data are unlikely to be directly applicable to gill net fisheries because the very different method of capture would likely influence post-release survival. Several authors estimated survival of fish after capture in gill nets followed by confinement in net pens (sockeye: Thompson et al. 1971; spotted sea trout: Murphy et al. 1995; lake trout: Gallinat et al. 1997, coho salmon: Farrell et al. 2001a and 2001b). However, evaluations of post-release survival of salmonids (*Oncorhynchus* sp.) held in the artificial confines of net pens are unlikely to reflect the post-release survival of free-swimming fish because fish held in net pens are not subject to normal post-release survival factors such as predation, currents, or encounters with obstacles to migration. Fish captured in commercial fishing gears show considerable stress (Farrell et al. 2000), and fish released free-swimming following capture would immediately contend with these additional stresses.

The results from our initial study in 2001 indicated that tangle nets could be used commercially for selective harvesting of marked spring chinook salmon on the Columbia River. Tangle nets proved to be as efficient capturing adult spring chinook salmon as the conventional 8” gill net, and had an acceptably low immediate mortality rate. In 2001, we found that the post-release mortality rate of spring chinook salmon released from the tangle net was about 1/6th that of fish released from the gill net. In addition, the fish harvested from the tangle net, having fewer net marks on their bodies, may realize higher market prices than fish captured in the gill net.
The main goal of the 2002 study was to continue to test the fundamental premise of commercial selective fishing – that released non-target salmon really do survive at acceptable levels to contribute to rebuilding the weak stocks they are part of, and that this is therefore an effective management strategy to protect weak stocks. We tested this for the second year by estimating the post-release mortality of spring chinook salmon released from tangle nets (4.5”) and 5.5” multi-strand nets on the Columbia River. The 5.5” net is considered by some in the industry to be a tangle net on adult chinook, so our study compared this net to a true tangle net (3.5”-4.5” multi-strand). We also estimated and compared the immediate mortality and catch efficiency of the two gears and evaluated characteristics of fish caught in each gear. Gear changes may result in encounters with different non-target species (by-catch), and this is expected with the tangle net as many small fish species that dwell in the Columbia River can pass through the large mesh gill

nets without incident, but would be captured in the smaller-meshed tangle net. Because it is undesirable to shift the impacts from one species to another, we also compared the capture of species other than spring chinook salmon in each gear.

Methods

The Columbia River is the second largest river in the United States, draining an area of 258,000 square miles. From its source in British Columbia to its mouth at the Pacific Ocean, the Columbia River flows 1,270 miles. Spring chinook salmon returning to the Columbia River encounter Bonneville Dam, the first mainstem hydroelectric dam, at river mile (RM) 146, and fish migrating upstream will encounter up to eight more mainstem hydroelectric dams before they reach the impassable Chief Joseph Dam at RM 545. Fish venturing up the Snake River, the largest tributary to the Columbia River, encounter seven more dams. Spawning grounds for spring chinook salmon are dispersed throughout the Columbia River basin, as are a number of hatcheries that produce spring chinook salmon for supplementation and harvest. Consequently, spring chinook salmon returning to the Columbia River belong to a number of stocks that also disperse as they migrate upstream. Harvest of spring chinook salmon occurs throughout the river and consists of commercial, tribal treaty, and sport fisheries.

We fished for returning adult spring chinook salmon at the following locations downstream (7 to 20 miles) of Bonneville Dam: near Ainsworth State Park (RM 139); near Shepherd's Dell State Park (RM 131); and near Cottonwood Point on the western end of Reed Island (RM 125).
We contracted local fishers to fish nets that were 75 fathoms of 4.5" mesh size tangle net (1.5 mm x 5 strands, hung at a ratio of 2:1) shackled to 75 fathoms of 5.5" mesh size net (1.5 mm x 6 strands, hung at a ratio of 2:1). The hang ratio describes the number of fathoms of mesh per fathom of cork line. Both gear types were hung to the same depth (35 ft) that was the suitable to each area being fished. The nets were light green. We fished during daylight hours and at night and tried to avoid fishing areas and times when anglers were present.

Fishers contracted for this project had many years of experience gillnetting for salmon in the study area and were asked to mimic the fishery pertaining to the location and as to how nets were deployed. We also asked the fishers to cover both sides of the river to ensure a representative sample of the various spring chinook salmon stocks present in the river. During each fishing session, we alternated the end of the net that was closest to shore so that the fishing effort of each net type was as similar as possible for each area fished. Each vessel was equipped with a hydraulic reel mounted in the bow that was used to deploy and retrieve the nets. The nets were set by reeling them across the river (typically in a curved pattern) and allowing both ends to drift freely. Observers selected the appropriate drift time for each set. The drift time was defined as the time from when the first cork went into the water until the first cork was removed from the water. All vessels were equipped with a recovery box similar to that described by Farrell et al. (2001a). The recovery boxes were aluminum with two compartments for holding fish. Each compartment was about 42" long, 15" high and 8" wide. The compartments of the recovery box were wide enough to allow a salmon to fit with its head facing the fresh water flow but narrow enough to prevent the fish from turning around. A submersible bilge pump or a 2" gas-powered water pump was connected to a discharge hose that supplied fresh water through tubes located near the bottom of the front section of the box. The front panels of the box where the tubes were attached for water flow were constructed to slide vertically. Lifting the panels provided a water slide so that fish could be released in a stream of water into the river. Overflow outlets were located at the opposite end of the recovery box.

Two observers were on board each vessel. One observer primarily recorded data, while the other observer handled fish. For each set, observers recorded the following: the time when the first part of the net was placed in and removed from the water; the time the shackle between the two nets was removed from the water; the time the end of the net was brought on board; the longitude and the latitude for the set (using a Magellan handheld GPS unit); which net type was put in the water first; and which net type was removed from the water first. Observers also recorded the date, skipper's name, boat name, observer names, set number, weather conditions, water and surface temperatures, presence of marine mammals, and any other observations pertaining to each particular set.

Observers informed fishers when to start picking up nets to ensure short soak times (the time from when the first cork goes in the water until the last cork is removed from the water). Fishers were instructed on proper fish handling as they removed fish from the net, particularly to avoid touching the gill area or holding fish by its caudal peduncle. As possible, fishers also looked over the bow as the net was being retrieved so they could lift fish over the roller. Fish were placed immediately into a tank of freshwater located near the bow. Any unusual observations about fish handling from net to tank were recorded. For each spring chinook salmon caught, the observer noted the net mesh size where it was captured (4.5" tangle or 5.5"), the type of capture, whether the adipose fin was missing, and the condition of fish at capture. The observer then measured the fork length and tagged the fish with a jaw tag covered with a plastic sheath and printed with a number. The plastic sheaths were color-coded to correspond to the net type in which the fish was captured. We characterized the type of capture as tangled by teeth or mouth, gilled (net around the gills), wedged (web around body further than gills), or mouth clamped (net wrapped around mouth, clamping it closed). A fish was initially ranked as condition 1 if it was lively and not bleeding, condition 2 if it was lively but bleeding, condition 3 if it was lethargic but not bleeding, condition 4 if it was lethargic and bleeding, and condition 5 if it showed no visible movement or ventilation. Fish ranked condition 1 or 2 were tagged and released overboard immediately. Fish in conditions 3 to 5 were held in the recovery boxes until they both recovered to condition 1 or 2, and could be released, or they died. We recorded if fish were placed into the recovery box and the condition at release, or when resuscitation failed and fish was determined to be dead. Loss of scales, damaged fins and other visible injuries were recorded. Non-target species encountered were counted according to the net mesh size where captured. For every steelhead salmon *(Oncorhynchus mykiss)* captured, we recorded the net type where captured, the type of capture, whether the adipose fin was missing, the condition of the fish at capture, fork length, and the sex. In addition, we estimated which third of the net (by depth) the steelhead salmon were captured in.

A control group of spring chinook salmon was collected and tagged with a colored jaw tag at the adult fish trap located in the fish ladder at Bonneville Dam on the Washington shore of the Columbia River. These fish had passed through all the same predatory pressures as the fish caught in the gears as well as similar fishing pressures, but had not been captured in our test gears. Because the fish captured by nets had also passed through one additional popular sport fishing area, pinniped predation, and successfully located and passed part way through the fish ladder, they may have an advantage compared to the spring chinook salmon released from the test gear that would be reflected as a higher post-release survival rate. In the trap, fish pass through a series of diverters and chutes and into a holding tank. Clove oil was added to the holding tank to temporarily anesthetize the fish. Each spring chinook salmon in the control group was then measured (fork length) and tagged. The observer recorded whether the fish was missing its adipose fin and any visible injuries. Fish were then transferred to a holding tank with fresh water until they revived back into lively condition and were released into a chute and diverted back to the fish ladder to continue their migration. Trapping occurred throughout the test fishery time frame to ensure the same populations of migrating fish were tagged in each group.

We evaluated long-term survival of released fish as they were recovered at hatcheries, sport and treaty harvest, and at spawning ground surveys. We also monitored the number of tagged spring chinook salmon passing up fish ladders of three dams: Bonneville, The Dalles, and John Day Dams. The dam facilities are each equipped with two viewing windows located at the fish ladders. Technicians stationed at the viewing windows reported a daily total of the different colored jaw tagged fish as they passed through the ladders. Posters were distributed requesting the following information: date of harvest, location of harvest, tag color, and tag number. They were posted at various locations to target both treaty and non-treaty anglers. Hatchery crews and stream surveyors returned the same information.

For each day we were able to fish both nets equally, we compared the catch per hour of adult spring chinook salmon in the 4.5” tangle net to the 5.5” net. Jack spring chinook salmon were captured, but are not as important either for marketing or for stock management, and so were omitted from this analysis. The fishing time included only the time the nets were actually fishing and not time spent preparing for the next set. Because we recorded only the time the first cork went in the water, and not when the shackle went in, we designated the time to set the first net as 3 minutes in every case. The total fishing time for each net was then calculated as the time from when the first cork of that net was placed in the water to the time when the last cork of that same net type was removed from the water. We calculated the total number of chinook salmon adults for the tangle and 5.5” net for each set. The total number of chinook salmon adults were summed with the set time for each net type by skippers for each day fished. The frequency distributions of spring chinook salmon by condition at capture were compared using a chi-square analysis ($P<=0.05$). Soak times, total drift times, fish lengths, and the numbers of non-salmonids in sets with and without dead fish were compared using t-tests ($P<=0.05$). To compare the post-release survival of spring chinook salmon released from each net, we chose to use the Z-statistic as described in Zar (1999) for comparing two proportions. To eliminate bias in how catch efficiency may be related to fish abundance, the catch efficiencies of each net type were compared using a sign test. Where appropriate, data were pooled among skippers and across fishing days to represent a more balanced picture of a fishing season.

RESULTS

IMMEDIATE SURVIVAL AND CONDITION

Test fishing began on April 1, 2002, and we fished 63 boat days (a boat day is defined as an individual boat-date combination) between that day and May 21, 2002. We captured 3,162 adult (including 65 recaptures) and 57 jack spring chinook salmon (with no recaptures; here defined as fish that are 60 cm fork length or less). Of those, 23 adults (0.7%) and 1 jack (1.8%) could not be revived following capture (Table 1). Of the fish that survived and were released, all but 17 adults and 1 jack were tagged, so that 1,218 chinook salmon captured in the tangle net were tagged and released, and 1,839 chinook salmon captured in the 5.5” net were tagged and released. Jacks were released untagged because their jaws were too small for correct application of the tag. We tagged and released 1,034 spring chinook salmon in the control group at Bonneville Dam throughout the test fishing period. No control group fish died during handling.

Table 1. Immediate survival (%) of adult and jack spring chinook captured including recaptures during test fishing in each net type on the Columbia River. N is the number of spring chinook encountered.

Net type	Adults		Jacks	
	% Survival	N	% Survival	N
Tangle	99.5	1262	97.2	36
5.5”	99.1	1900	100	21

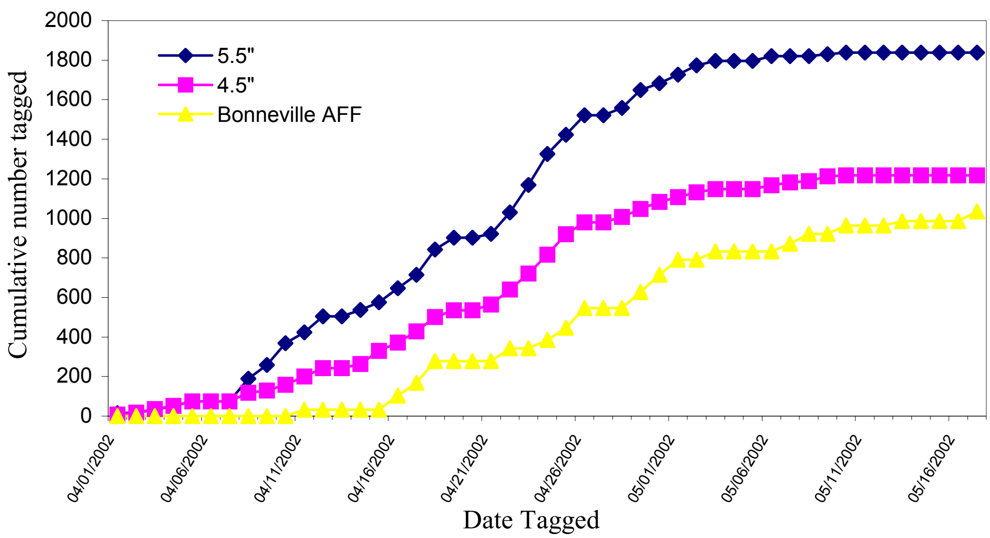

Figure 1. Cumulative number of spring chinook salmon tagged and released during test fishery below Bonneville Dam using the 4.5" tangle and 5.5" nets, and at the adult trapping facility in Bonneville Dam.

The later start in capturing control fish was thought to coincide with migration timing from the site of treatment capture and the dam site (site of control capture). Sixty-five (2.1%) tagged and released adult spring chinook salmon were recaptured during the test fishery, with 31 recaptured in the 4.5” tangle net and 34 recaptured in the 5.5” net. Six spring chinook salmon, each from the 4.5” tangle and 5.5” nets were also recaptured and then released from the control site. The time between the initial capture and recapture ranged from 51 minutes (a subsequent set on the same day) to 551 hours (about 23 days). All of the fish that were recaptured, survived and were released in good condition.

The initial condition of each fish was scored as the fish was brought onboard. The distribution of the condition of adult spring chinook salmon in each category was significantly different between the tangle net and 5.5” net (chi square=80.2, df=4, P<0.0001), with the tangle net having a larger proportion of fish captured in condition 1 and the 5.5” net having a larger proportion of fish captured in condition 3 (Table 2). Fish captured in condition 1 in the tangle net were typically captured by tangling. Fish captured in condition 3 in the 5.5” net were also typically captured by tangling.

Table 2. Adult spring chinook salmon (including recaptured fish) scored in each condition category at capture that were released (Rel’d) or died for the 4.5" tangle net and the 5.5" net.

Net Type	Condition At Capture									
	1 Lively		2 Lively, bleeding		3 Lethargic		4 Lethargic, bleeding		5 No visible movement or ventilation	
	Rel’d	Died	Rel’d	Died	Rel’d	Died	Rel’d	Died	Rel’d	Died
Tangle	1009	0	43	0	176	1	9	0	19	5
5.5”	1251	0	48	0	507	9	21	2	48	6
Total	2260	0	91	0	683	10	30	2	67	11

The proportions of fish caught by the different capture types were significantly different between the two net types (chi square=181.0, df=3, P<0.0001) (Table 3). The tangle net had a significantly higher proportion of tangled fish and the 5.5” net had a significantly higher proportion of gilled fish (chi square=98.8, df=1, P<0.0001; chi square=173.6, df=1, P<0.0001; respectively.)

Table 3. Capture types of adult spring chinook salmon (includes recaptures) that were released (Rel’d) or died.

Capture Type	Net type			
	Tangle		5.5”	
	Rel’d	Died	Rel’d	Died
Gilled	2.0 %	0	17.4 %	10
Mouth Clamped	11.2 %	2	10.7 %	3
Tangled	86.0 %	4	70.6 %	4
Wedged	0.8 %	0	1.3 %	0
Total	1255	6	1872	17

The distribution of visible injuries (e.g., net marks, pinniped wounds) observed on salmon captured in the tangle net was overall significantly different from the 5.5” net (chi square=36.08,df=5,P<0.0001), (Table 4). The main difference between observed injuries was the higher proportion of fish in the 5.5” net with net marks on their head. Of the fish captured in the 5.5” net, 44.7% had net marks on their head compared with 38.8% in the tangle net.

Marine mammals and sea lions are common in the lower Columbia, and the impact they have on salmon in commercial gear is a concern. Roughly, 50% of all of our sets during the test fishery had observed marine mammal presence and 33% of all the sets had fish with marine mammal wounds. The occurrence of marine mammal wounds on the fish was relatively equal between the tangle net and 5.5” net (12.5% and 11.2% respectively). These wounds ranged from scars to open wounds with substantial tissue trauma.

Fish in conditions 1 or 2 were tagged and released overboard with minimal holding. We attempted to recover fish in conditions 3, 4, or 5 to condition 1or 2 for release. Holding times in the recovery box was not calculated, but most fish showed a quick improvement in condition. We successfully recovered and released 97% of adult spring chinook captured in conditions 3, 4, or 5 in both the tangle net and the 5.5” net.

Table 4. Occurrence of visible injuries (%) on fish captured in each net type. The other category contains low occurrences of torn gills, torn operculum, and hook wounds.

Net type	Descaling	Net marks-body	Net marks-head	Marine mammal wounds	Torn fins	Other
Tangle	21.7	7.5	38.8	12.5	18.6	0.9
5.5”	20.5	5.8	44.7	11.2	15.2	2.6

During the test fishery, 23 adults died before they could be released overboard. The mean fork length of the dead adults (72 cm, N=19) was significantly different from the mean fork length of the live adults (75.2 cm, N=3,043; t=3.63, df=19, P<0.05). The dead adults were captured in sets that had significantly longer set times than average (t=2.29, df=17, P<0.05). The total soak time-the time from when the first cork goes in the water until the last cork comes out-for the sets with dead fish varied from 31 minutes to 62 minutes, with an average soak time of 44 minutes (N=17 sets). The total soak time for all sets varied from 24 minutes to 65 minutes with an average of 39 minutes (N=352 sets).

The tangle net did capture many more non-target species than the 5.5” net (Table 5). The actual numbers of non-salmonids are likely underreported because this was not the primary goal for the observers. Sturgeon were generally released in good condition, while the condition of the other species was variable.

Table 5. Count of non-target species in the tangle net and 5.5" net caught during the test fishery on the Columbia River. "Other" includes: walleye, flounder, carp, bass etc, for which only a small number were encountered.

Species	Tangle net	5.5" net
Shad	397	23
Northern Pike Minnow	86	9
Sturgeon	494	276
Sucker	203	18
Other	33	6
Total	1,213	332

The relationship between the increased number of non-salmonids and increased immediate mortality may be an important factor in a tangle net fishery because the time needed to extract bycatch may increase the immediate mortality of salmonids. However, for 2002 the number of dead salmon in sets with bycatch animals in them (4 per set, N=17 sets), and the sets that did not have dead salmon in them was not significantly different (4.3 per set, N=359 sets; t=0.20, df=374, P>0.05).

The water surface temperatures during test fishing ranged from 4ºC to 11ºC. The mean water surface temperature for sets with dead fish in them was 9ºC (N=16), not significantly different from the mean water surface temperature for all sets (8.9ºC, N=270 sets; t=1.56, df=32, P>0.05), therefore water surface temperature did not appear to affect immediate survival in this study.

Post release survival

We tagged and released 1,218 spring chinook salmon from the 4.5" tangle net and 1,839 from the 5.5" net. We also tagged a control group of 1,034 at the Adult Fish Facility at the Bonneville Dam. Tags were recovered throughout the Columbia River in sport fisheries, commercial fisheries, at hatcheries, and on spawning grounds (Figure 2). The first tag was recovered on April 2,2002, and the last was recovered on October 8, 2002. Figure 3 shows the breakdown of jaw tag recoveries by fishery and return to natal stream over time. As could be expected, most of the initial recoveries were from fisheries, and the latter recoveries were typically from spawning ground surveys and hatcheries. Not all of the tag colors were reported, and some of the tag numbers were illegible, such that some tags could not be assigned to the original net they were captured in, or to other subcategories identified at the time of capture (capture type, condition at capture, etc.). Of the recovered tags, only one could not be assigned to the capture type or to other subcategories. Nine control tags, eighteen 5.5" net tags, and six tangle net tags could not be assigned to subcategories.

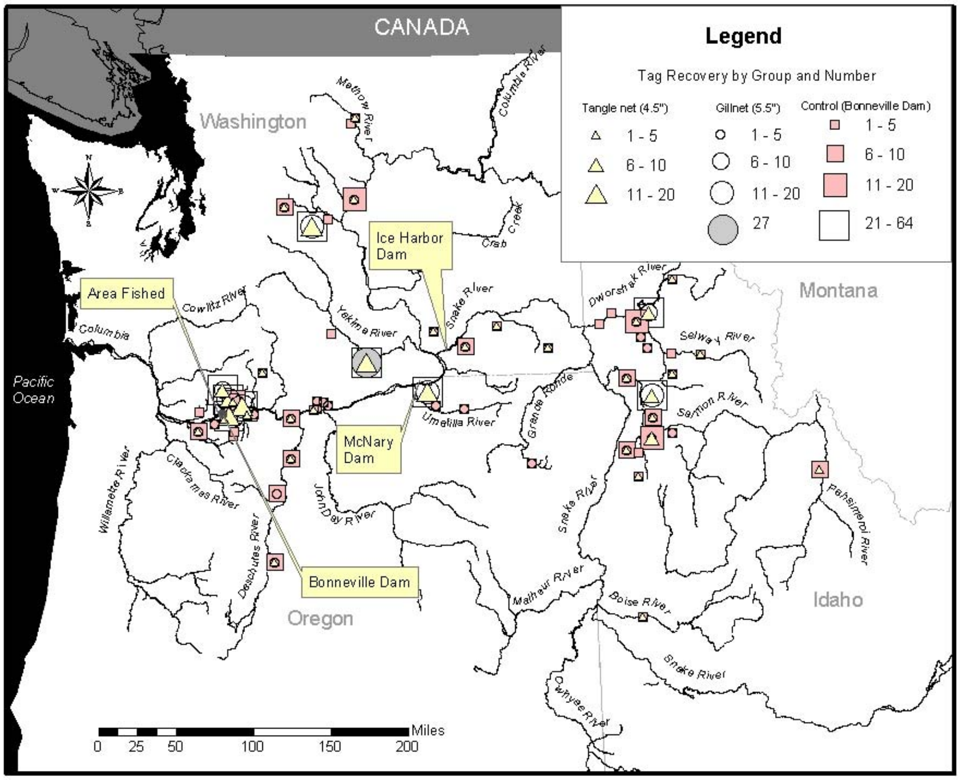

Figure 2. Recovery locations of spring chinook salmon captured and released from 4.5" and 5.5" nets and from the Adult Fish Facility at Bonneville Dam (controls). The "area fished" denotes the location where the test nets were fished and tagged fish were released from the test nets.

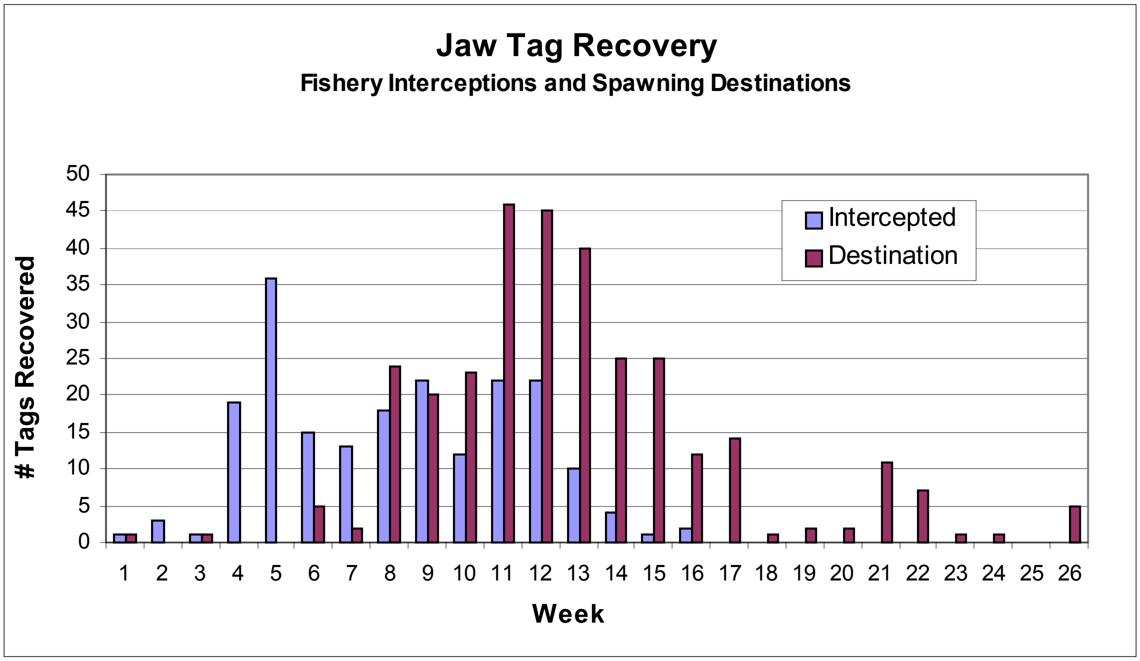

Figure 3. Number of jaw tags recovered through interception (fisheries) and destination (spawner surveys and hatcheries) by test fishing week.

Most recovered fish were reported in good condition. Recoveries were clumped in areas with popular sport fisheries and at hatcheries. These are the areas with the most intensive sampling, but do not indicate that tagged fish did not return to other areas. We assumed that treatment fish captured in the nets and control fish captured at the Bonneville Dam were from the same populations, and therefore their tags were equally likely to be recovered, so that observed differences in tag recovery rates were due to survival differences. Figure 2 and Appendix B show the distribution of treatment and control fish by recovery area. To further evaluate the assumption that treatment fish and control fish were from the same population, the recoveries were broken down by geographic region (Table 6). A chi square test showed a borderline significant difference for treatment and control recoveries by region (chi square =7.72; P=0.052.) The significance was largely due to fewer recovered controls than expected in the Snake River above Ice Harbor Dam Region.

Because treatment fish were captured below the Bonneville Dam while control fish were captured after they had migrated partway through the Bonneville Dam, there were concerns that the treatment fish might consist of more "below Bonneville" spawners than the control fish. To test this assumption, we looked at the proportion of recoveries below Bonneville Dam between the treatment and control groups. A chi square test failed to show a significant difference for treatment and control recoveries for this region (chi square=1.90; P=0.17.) Consequently, the experimental evidence supports the assumption that the treatment and control groups represent the same populations.

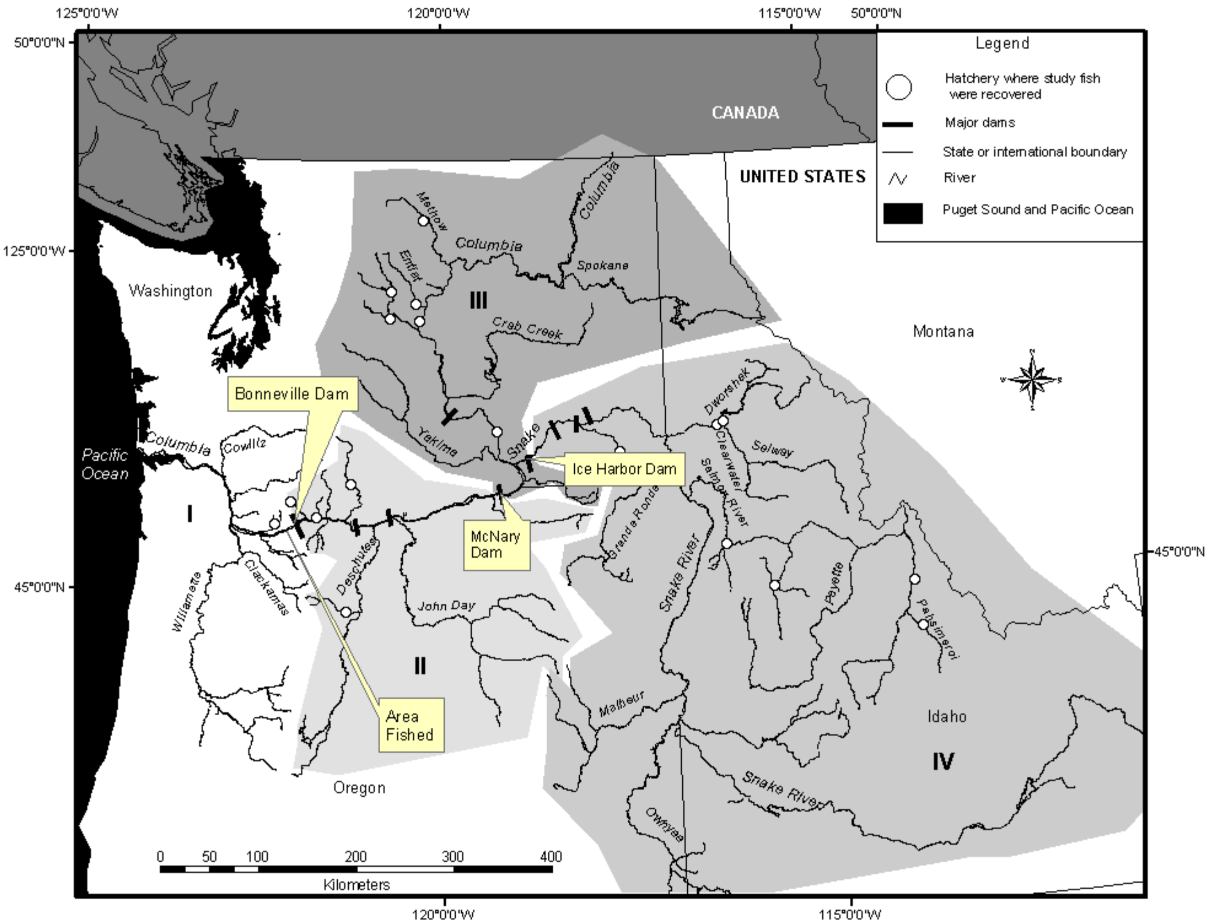

Figure 4. Geographic areas where fish were recovered: I-Below Bonneville Dam; II-Between Bonneville and McNary Dams; III-Upper Columbia above McNary Dam; and IV-Snake River above Ice Harbor Dam.

Table 6. Spring chinook salmon released, number recovered, and percent distribution by geographic area in 2002.

Region	Group	Both nets	Net percent distribution	Control	Control percent distribution	Total
	Number of fish released	3057		1034		4091
I	Recoveries below Bonneville Dam	10	2.6	2	0.9	12
II	Recoveries Bonneville Dam to McNary Dam	164	42.8	110	52.1	274
III	Recoveries Columbia R. above McNary Dam	103	26.9	57	27.0	160
IV	Recoveries Snake R. above Ice Harbor Dam	106	27.7	42	19.9	148
	Total	383	100.0	211	100.0	594

The control group of fish was assumed to be subject to all the same natural mortality as the test groups, except to the effects of capture in the nets. Further, we assumed that recovery and reporting rates were the same among the survivors of the two groups. Therefore, relative to the survival of the control group we estimated that 67.6% of the test fish released survived their tangle net experience, while 57.3% of the test fish released survived their 5.5”net experience (Table 7.) The delta method of variance was used to obtain the confidence intervals around the point estimate (Appendix C).

Under the assumption of equal reporting rates, the difference in recovery rates would be attributed solely to survival. Consequently, the survival difference between the two nets was done with a more powerful test, the Z test of proportion of recovery rates, which simply compares the recovered proportions. This method is more powerful because it bypasses the need for the control fish and therefore does not need to account for the uncertainty introduced by the control recoveries. Significantly more spring chinook salmon were captured and released from the 4.5” tangle net were recovered than those captured and released from the 5.5” mesh net ($Z=1.72$; $P=0.043$).

Table 7. Recovery of tag groups from hatcheries, fisheries, and spawning grounds.

Group	Number Tagged	Number Recovered	Percent Recovered	**Relative Survival Rate**	95% confidence interval for relative long-term survival rate
Bonneville Controls	1034	211	20.4%	**100%**	N/A
5.5" Net	1839	215	11.7%	**57.3%**	48.1-68.2%
4.5" Tangle Net	1218	168	13.8%	**67.6%**	56.1-81.3%

Using our calculated point estimates of survival to demonstrate the difference, we expect that for every 1000 spring chinook salmon caught in the 4.5” tangle net that must be released, 5 would die immediately (1000*0.005=5), and another 322 ((1000-5)*0.324=322) would die after release, for a total kill of 327 fish. Using the 5.5” net; for every 1000 spring chinook captured that must be released, 9 would die immediately (1000*0.009=9), and another 423 ((1000*0.009)*0.427=423) would die after release, for a total kill of 432 fish. Therefore, about 1.3 times as many spring chinook salmon could be handled and released from the tangle net for the same mortality caused by the 5.5”net. These rates would only be expected with the gears and the careful handling techniques we used.

Fish tagged in each of the three main test fishing areas were subsequently recovered somewhere in the Columbia River Basin (Figure 5). The tag recovery rate varied among skippers and among areas they fished, with the highest recovery rate being from the lowest site. The sample size was small (9 fish) so this is likely a coincidence. The recovery rates for the middle and uppermost sites were about the same (12.3% and 11.3% respectively).

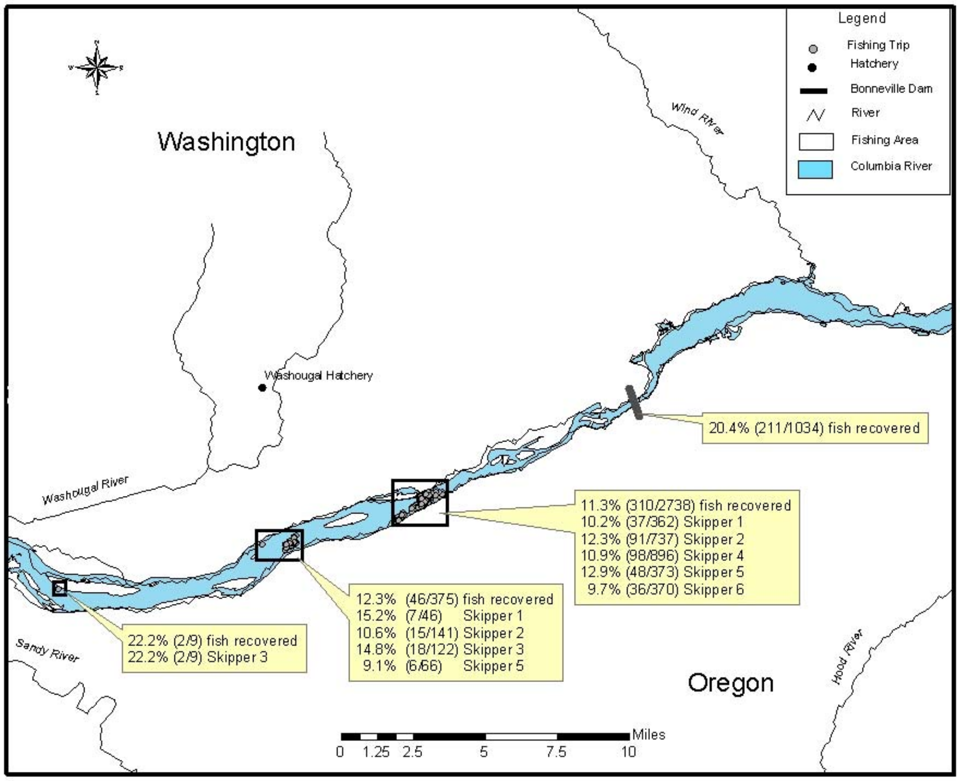

Figure 5. Percentages of tagged fish from each fishing area that were subsequently recovered, by skipper.

We recovered tags from spring chinook captured in each condition category, but those captured in condition 1 were disproportionately represented in the recovered tags. At capture, 80.5% of the 4.5" tangle net fish were in condition 1, while 84.6% of the recoveries were from those condition 1 fish. Similarly, at capture 66.6% of the 5.5" net fish were in condition 1, while 73.6% of the recoveries were from those condition 1 fish. This suggests that although fish captured in other conditions can be recovered to a state where they appear to be in condition 1 at release, they may not have fully recovered physiologically. There was not a significant difference in mean fork length at release between the fish that were recovered (75.7 cm, N=343) and those not recovered (75.8 cm, N=2678).

CATCH EFFICIENCY

The tangle net was significantly less efficient over the course of the test fishery (Wilcoxon signed rank test; T=36, t=525, P<0.05). There were seven days of equal observed efficiency and eight days when the tangle net observed efficiency was slightly larger (**Figure 6**). The catch per hour of the tangle net remained relatively constant throughout the test fishery, while the 5.5"net efficiency was higher in the earlier period of the fishery and lessened in the later period (**Figure 6**).

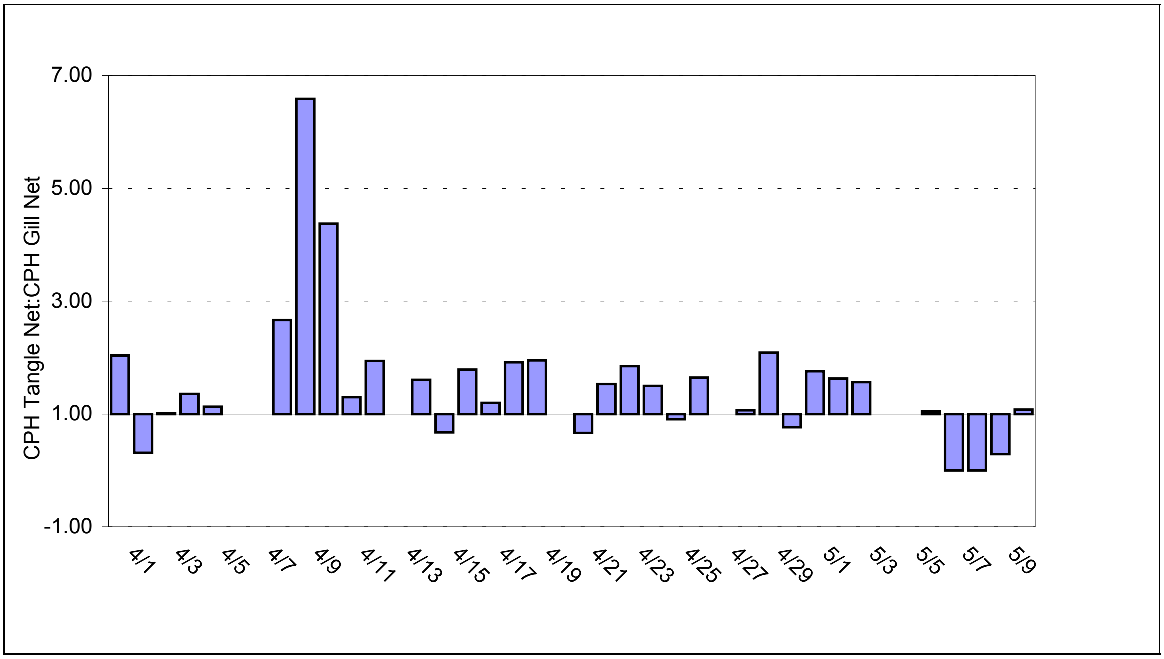

Figure 6. Relative catch of adult spring chinook salmon per hour (CPH) for the tangle net compared to the 5.5"net. Values at 1 indicate equal efficiency, while those below indicate when the tangle net was more efficient, and those above 1 indicate when the 5.5" net was more effective. Paired sets were pooled by day across skippers.

The highest numbers of spring chinook passed over Bonneville Dam between April 19 and May 10, 2002 (**Figure 7**). Allowing a few days for travel, the highest densities of fish were likely available to us between April 12 and May 3, 2002.

Table 8. Capture of adult spring Chinook salmon per hour (CPH) during comparable sets for each net type.

Net type	Min CPH	Max CPH	Average CPH
Tangle	1.6	14.1	6.2
5.5" Net	0.0	22.6	9.2

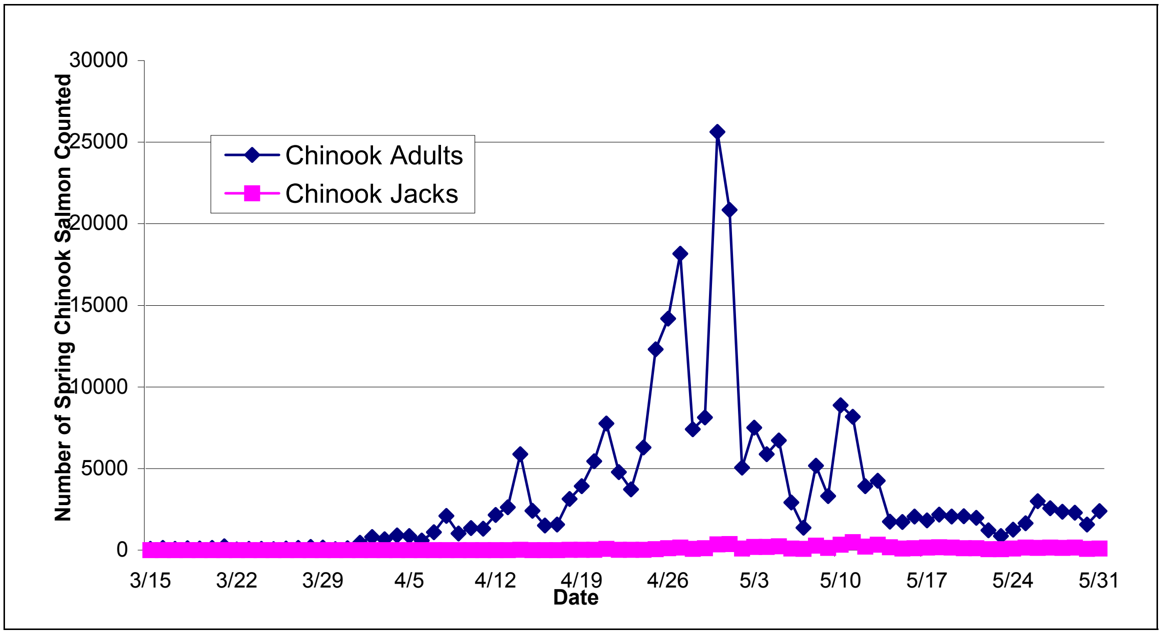

Figure 7. Number of adult and jack spring chinook salmon counted at the counting windows at Bonneville Dam, 2002; Army Corps of Engineers.

SIZE OF ADULTS CAPTURED

There was a small but significant difference between the average fork length of adult spring chinook salmon captured in the tangle net (76.3 cm, N=1221) and those captured in the 5.5"net (75.4 cm, N=1819; t=3.39, df=2707, P<0.001).

JACK SPRING CHINOOK SALMON

We captured 57 jacks (here defined as small or immature chinook salmon 60 cm fork length or less) during the test fishery. Of those, 63% were captured in the tangle net and 37% were captured in the 5.5" net. Immediate survival was 98%. Jacks captured in the tangle net (N=36) were mainly captured by gilling (44.4%) or being wedged in the net (30.6%). Jacks captured in the 5.5"net (N=21) were mainly captured by being wedged in the net (47.6%) or tangling (42.9%). Seventy-seven point two percent of the jacks were brought on board in condition 1, with the rest mostly in conditions 2 and 3. We were able to revive all but one of the jacks captured; this fish was gilled in the tangle net. Sixty-one point four percent of the jacks brought on board were descaled, compared to only 21.2% of the adults captured during the test fishery.

PASSAGE OVER BONNEVILLE, THE DALLES, AND JOHN DAY DAMS

The first jaw tagged spring chinook salmon was observed passing Bonneville Dam on April 7, 2002, and the final jaw tagged spring chinook salmon was observed on May 30, 2002. The highest count of jaw tagged fish passing through the windows occurred on April 30, 2002, and the median date was May 3, 2002. Technicians at Bonneville, The Dalles, and John Day Dams recorded daily totals through June 30, 2002. From the three dams combined, 5,530 jaw tagged spring chinook salmon were observed passing upstream.

Because of limited color availability from the manufacturer, we used the same color jaw tags (red for control fish, yellow for tangle net caught fish, and white for 5.5" net caught fish) as for the previous year. Because of discrepancies in the ability to denote differences between the tag colors at the observer windows in the dams, we did not separate the observed tags by net type (tag color). Fortunately, evaluating passage through dams was not as important as evaluating long-term survival through tag recoveries. We assume certain anomalies in the data as in the previous year.

STEELHEAD SALMON BYCATCH

We captured 54 steelhead salmon during the test fishery. Of those, 63% were caught in the 4.5" tangle net and 37% were caught in the 5.5" net. Steelhead captured in the 4.5" tangle net (N=34) were captured by tangling (61.8%), gilled (17.6%), mouth clamped (11.8%), and wedged (8.8%). Steelhead captured in the 5.5" net (N=20) were captured by tangling (70%), wedged (15%), gilled (10%), and unknown (5%). Most fish brought on board ranked in condition 1 (59.3%). The remaining fish ranked as listed: condition 2 (3.7%), condition 3 (25.9%), condition 4 (5.56%), and condition 5 (5.56%).

No fish died during handling and all were released in good condition. From total fish captured, 37% (N=20) were placed in the recovery box before they were released in conditions 1 or 2. Most common injury observed was net marks on the head (37%). Of those, 65% of the injury occurred from fish captured in the 4.5" tangle net and 35% from fish captured in the 5.5" net.

Twenty-two steelhead salmon were encountered during the 2001 selective gear test fishery, and all were released in excellent condition (Vander Haegen et al., 2002). However, because it is undesirable to shift the impact from one species to another, we estimated the depth at which steelhead captures occurred during our test fishery in 2002. The 35' depth net used during test fishing was sectioned into thirds: first (about 12' depth from cork line down); middle (about 12' to 24' depth); and last (about 24' depth down to lead line). We recorded the section of net steelhead were being captured. Thirty-five percent of fish (N=19) were caught in the first section, 33% of fish (N=18) were caught in the last section, 20% of fish (N=11) were caught in the middle section, and 11% of fish (N=6) were determined unknown.

There was no significant difference in fork lengths of steelhead caught in the 4.5" tangle net and the 5.5" net, (t test, $P>0.05$).

COMPARISON WITH PREVIOUS YEAR'S RESULTS

In the 2001 study, we compared a 4.5" tangle net with an 8" gill net. This difference was significant (one tailed $Z=3.05$, $P=0.001$.) In the 2002 study, we compared a 4.5" tangle net with a 5.5” net. Consequently, we did not expect to see as great a difference between the two treatments in 2002 as we did in 2001. The one tailed Z test for the overall survival of spring chinook salmon released from the tangle and 5.5” gears was still significant (Z=1.72; P=0.043.) We were initially surprised to see a greater mortality point estimate for tangle net captured fish in the 2002 study. Various comparisons were made between the 2001 and 2002 years to try to understand the survival variation between years. We compared bycatch, geographic distribution by treatment, day and night fishing, marine mammal presence and predation, and confidence intervals. We also considered spill over the Bonneville Dam. Some but not all of these categories were expected to shed light on the greater mortality point estimate for the 2002 study tangle net captured fish.

Bycatch

In the 2001 study, we found that the concentration of bycatch in sets had a negative influence on the number of dead fish in those sets. However, in 2002, we did not see this. Less bycatch were captured during the 2002 test fishery, which likely resulted from fishers avoiding fishing in locations and at times when shad and sturgeon were more likely to be captured.

Geographic distribution

A main assumption for this study is that treatment and control fish are from the same populations and therefore their tags are equally likely to be recovered, so that observed differences in tag recovery rates are due to survival differences. Table 9 shows the recoveries broken down by geographic region. A chi square test failed to show a significant difference for treatment and control recoveries by region (chi square =2.15; P=2.15.) Because treatment fish were captured below the Bonneville Dam while control fish were captured after they had migrated partway through the Bonneville Dam, if a difference between the two populations existed, the region below Bonneville Dam should show a significant difference. However, a chi square test failed to show a significant difference for treatment and control recoveries for this region (chi square=0.64; P=0.64.) Consequently, the experimental evidence indicates the treatment and control groups represent the same populations.

Table 9. Spring chinook salmon releases, recoveries, and percent distribution by geographic area in 2001.

Region	Group	Both nets	Net percent distribution	Control	Control percent distribution	Total
	Number of fish released	1324		1196		2520
I	Recoveries below Bonneville Dam	4	3.7	3	2.12	7
II	Recoveries Bonneville Dam to McNary Dam	39	36.4	44	30.3	83
III	Recoveries Columbia R. above McNary Dam	53	49.5	78	53.8	131
IV	Recoveries Snake R. above Ice Harbor Dam	11	10.3	20	13.8	31
	Total	107	100.0	145	100.0	252

Day and night fishing

There was a significant difference in day and night fishing between years (chi square =37.06; P<0.0001). During 2001, we fished more often at night (91.8% of sets) than during the day (8.2% of sets). During 2002, we fished relatively often during the day (52.4% of sets) than at night (47.6% of sets). For both years, there was no significant difference in the recovery rate of fish released at night versus fish released during the day (for 2001 chi square = 0.08l P>0.05 and for 2002 chi square = 0.12; P>0.05).

Marine mammal presence and predation

In 2002, 49.3% of the sets had marine mammal observations. Thirty-three point five percent (120/359) of the total sets had at least one fish with a marine mammal injury. In 2001, 10.7% of the sets had marine mammal observations. Forty-six point eight percent (131/280) of the total sets had at least one fish with a marine mammal injury.

Confidence intervals

Confidence intervals for the 2001 long-term survival results were recalculated and compared to the 2002 long-term survival results using the delta method (Table 10). Although the tangle net survival estimates varied during 2001 and 2002, the confidence interval calculation shows an overlap in survival for both years. The confidence interval calculation is shown in Appendix B. The confidence interval shows a slight overlap in survival for the tangle and 8” gill net in 2001 and a greater overlap in survival for the tangle and 5.5” net in 2002.

Table 10. Comparison of long-term adult mortality and confidence intervals for tangle, 8” gill and 5.5” net captured spring chinook salmon in 2001 and 2002.

Study year	Study group	Relative long-term adult mortality %	Confidence interval
2001	Tangle net (3.5” & 4.5”)	9.0	0.0-53.0
2001	Gill net (8.0”)	47.5	42.1-52.9
2002	Tangle net (4.5”)	32.4	26.7-38.7
2002	5.5” net	42.7	35.5-49.9

Spill over Bonneville Dam

The year 2001 was one of the lowest flow years on record for spill over Bonneville Dam. Although the spill during 2002 was average, spill tests occurred during 2002 that put high volumes of water over the dam within short time periods.

DISCUSSION

This experiment is the second year we evaluated the post-release survival of free-swimming spring chinook salmon released from commercial fishing nets. Our results indicate that tangle nets can be suitable for mark-selective commercial fisheries on the Columbia and that gear type is important to spring chinook salmon post-release survival.

TANGLE NET

For both years, the 4.5” tangle net combined with modified fishing and handling practices reduced the post-release mortality of spring chinook salmon considerably. Tangle nets can be as efficient at capturing adult spring chinook salmon as gill nets, they have an acceptably low immediate mortality for fish brought on board, and we were able to show that the post-release mortality of spring chinook salmon released from the tangle net is lower than for fish released from a gill net. In addition, because they have reduced incidence of net marks on their bodies (or the associated internal injuries), spring chinook salmon captured in a tangle net may realize higher market prices than fish captured by gill net.

We observed a considerable difference in our estimate of the post-release survival of fish captured in the tangle nets in 2001 and in 2002. However, these estimates have high uncertainty. The high uncertainty suggests that several years of data should be collected before survival estimates are applied to untested years. We observed a difference in marine mammal presence between 2001 and 2002, but in 2001 most of the fishing occurred at night. In the dark, the potential for these predators to be present but not observed is more likely. Our fish handling techniques likely would have improved during the second year, so we do not believe that this is a contributing factor. We didn’t advertise which tag color represented any group and consequently do not believe there was any bias in reporting tags of a particular color. Although we are unaware of any published reports showing a difference between spill and the consequent survival effect it may have on adult spring chinook salmon, Peery et al. (personal communication) have results from telemetry studies that indicate spill may influence adult survival. If confirmed, spill will be another variable for fishery managers to consider when setting fishing seasons.

Shortcomings of the tangle net include that it captures many more non-target species than a conventional gill net and that fishers using the tangle net must learn and use careful handling techniques to maximize survival of released fish. These techniques include significant changes to fishing practices, which are difficult to enforce. Finally, fishers are required to make a capital investment that includes new nets, recovery boxes and other related equipment, as well as additional time needed to develop markets.

5.5” NET

In 2002, we compared a 4.5” tangle net to a 5.5” net because the 5.5” net was adopted by fish managers for the commercial fishery to reduce cost (commercial fishers typically use 5.5” mesh nets for other species). The 5.5” net appeared to capture fish in a manner intermediate to the tangle net and the 8” gill net that was used in the 2001 study. The capture methods showed increased gilling and wedging compared to the tangle nets, but not as great as for the 8” gill net. Fish captured in the 5.5” mesh net behaved more similarly at capture to fish captured in the 4.5” mesh net. Although we observed that fish released from the 8” gill net tended to be lively, difficult to hold, and generally fighting to get out of the holding tanks, spring chinook salmon released in both years from the 4.5” and in 2002 from the 5.5” net were noticeably calmer, and seemed even to be in a slight stupor. Following the reasoning used in our previous report, spring chinook salmon captured in the 4.5” and 5.5” and nets were therefore likely less physiologically exhausted than fish captured in the 8” gill net. Farrell et al. (2001) showed that coho salmon captured in commercial gill nets were physiologically exhausted and stressed because of capture. In contrast, spring chinook salmon coming on board from the 4.5” and 5.5” mesh nets would be in much better physiological condition at release, and better able to avoid predators, navigate barriers, and adapt to changing currents than tired fish. This hypothesis could be tested by analysis of stress hormones and lactic acid in blood samples from spring chinook salmon brought on board from each gear. Testing this hypothesis could also indicate if the 5.5” mesh net captured fish were intermediate in physiological condition to 4.5” and 8” captured fish. The 5.5” net did not result in as much scale loss and net marks as we observed for fish captured in the 8” gill net in 2001. This also indicates the 5.5” net was intermediate to the tangle net and conventional 8” mesh. In the 2001 discussion, we mentioned two possible reasons why the fish released from the tangle net survive better than the fish released from a gill net and these same arguments likely apply to the 5.5” net. First, unlike those caught in the tangle net, fish captured in larger mesh nets may sustain considerable external injury in the way of scale loss, skin abrasion and loss of the protective slime layer when they are captured in the body. We suspect that some of these injuries impair the fishes’ ability to fight off disease, particularly the ubiquitous *Saprolegnia* spp. fungus (spring chinook salmon migrating to the Columbia River generally enter the river about 4-5 months before spawning), osmoregulate, and successfully navigate the river.

CONTROL FISH

Our control fish had passed through all the same predatory pressures as the fish caught in the gears as well as similar fishing pressures, but had not been captured in our test gears. The control we used did not hold fish in place, such that they were more vulnerable to pinniped predation. This increased the quality of the control because harvest methods which hold a fish in place in the water likely to increase a fish’s vulnerability to pinniped predation. There were no tributaries between the fishing site and the trap where fish may have turned away. However, because the fish captured in the trap had also passed through one additional sport fishing area at the tailrace of the dam and had successfully located the fish ladder, they may have had an advantage compared to the spring chinook salmon released from the test gear that would be reflected as a higher post-release survival rate. While this would affect the actual survival estimates, the effect on each gear type would be the same, and thus the relative survival of fish from each gear type would not be affected.

RECOVERY, POST-RELEASE SURVIVAL, SPAWNING SUCCESS AND RECAPTURE

As we saw last year, the two-chambered recovery boxes used for lethargic fish were effective for recovering spring chinook salmon. Farrell et al. (2001a) found these types of recovery boxes effective for recovering coho salmon, although we were unable to achieve the 93.5% recovery of fish captured in gill nets in condition 5 (no visible movement or ventilation) that they observed. The reason for this difference is unclear, but may be a species difference, or because of the capture method. We also found that although a fish was observed to recover to a lively condition in the box, this did not necessarily mean the fish would survive after release, likely because a true physiological recovery requires much longer than the time for which we held fish, and much longer than would be practical in a competitive fishery. Post-release survival could probably be improved by holding fish for as long as possible, especially if the fish was brought on board in very poor condition, or by holding the fish in a cage alongside the vessel to promote active swimming during recovery (Farrell et al. 2001b). However, lengthy holding times might not be practical under commercial fishing conditions.

Holding fish in net pens for short periods is often used to represent the post-release mortality of free-swimming fish, because most fish are thought to die within a short time of capture. There is a clear discrepancy between that concept and our estimates of post-release mortality. We discussed in our 2002 report that our results differ from studies measuring post-release mortality by holding fish in net pens (Farrell et al. 2001a, 2001b; Gallinat et al. 1997; P. Frazier, unpublished data). Buchanan et al. (2002) showed improvements in the immediate survival of coho salmon bycatch from a gill net when using modified gear, short net soak times, careful handling of fish and a recovery box. In particular, mortality reduction was associated with shorter soak times. To evaluate post-release survival, these researchers conducted swim tests and found the fish attained a velocity comparable to speeds of physiologically recovered fish (Farrell et al. 2001a). Gallinat et al. (1997) found mortality of lake trout captured and released from gill nets varied seasonally between 23% and 32% after 48 hours of holding. Holding spring chinook salmon in net pens on the Columbia River for 72 h after capture in 8 inch mesh gill nets showed 7% mortality while 3% of those captured in tangle nets died (P. Frazer, personal communication). Our data indicate a much greater relative post-release mortality rate than is indicated by holding fish in net pens. Consequently, either additional stress is encountered when fish are released to swim freely or mortality occurs over more than a few days following capture. Certainly, our results suggest caution in using holding mortality to represent post-release mortality.

We found that although tangle, 5.5”, and 8”gill nets have high immediate survival rates, the post-release survival is different between gear types. This suggests we may see further differences between spawning success, (i.e., reproduction and gamete quality) for fish captured in these gear types. The stress response can be maladaptive to reproductive fitness (Shreck 2000), so while spring chinook salmon may survive capture and release, their ability to reproduce may be impaired, countering the potential conservation benefits of increased survival. Spring chinook salmon spawn about four months after the fishery occurs, which could give them time to recover and resume the reproductive process. We recommend experiments examining the physiological responses of spring chinook salmon to capture and the resulting effects on reproduction.

Comparable to the previous year's study, the low frequency of recaptures for fish captured in both net types suggests that the potentially cumulative effects of multiple recaptures on survival may be minimal. If many boats are fishing close to one another, the rate could increase so care should be taken to release fish away from other fishers.

The reason for the borderline significance of the chi square test between treatment and control recoveries for the 2002 study is unclear. The test showed that the Snake River above Ice Harbor region recovered fewer controls than expected (42 instead of 53). A possible reason for this discrepancy is that the University of Idaho research group selectively removes previously tagged (with passive integrated transponder or PIT) fish from the trap at the Bonneville Dam. These removed fish receive a telemetry tag and are not available to serve as controls in our study. The 2001 chi square test was not significant. Further, the 2002 and 2001 chi square tests testing the treatment and control populations for more lower river populations being captured in the treatment group were not significant. Consequently, unless further evidence is provided to reject the null assumption, it seems reasonable to conclude the treatment and control populations were the same.

CONCLUSIONS

The 2001 and 2002 experiments represent the first studies we know of that evaluate the post-release survival of free-swimming fish released from commercial fishing nets. These experiments show that immediate survival is very different from long-term survival and indicate that capture method may be critical to spring chinook salmon survival. Although the immediate mortality was less than 4% for all gears, we observed more than a 4-fold decrease in post-release mortality of spring chinook released from the tangle nets compared to the 8" gill net. The tangle net therefore warrants consideration for selectively harvesting hatchery spring chinook salmon on the Columbia River while still providing some protection of wild stocks. Because of the variable long-term survival estimates among years and the high uncertainty, further years are required to obtain a more precise survival estimate. Coupled with the careful fishing and handling procedures we used, the tangle net would likely be useful for selective harvest of other salmonid species, and in other areas. With the greater catch efficiency and lower capture of non-salmonids compared to the 4.5" tangle net and calmer behavior and reduced scale loss compared to the 8" gill net, the 5.5" net could be a useful choice in some fisheries. During the commercial spring chinook fishery that occurred lower in the river during 2002, many steelhead salmon (*Oncorhynchus mykiss*) were captured in the 5.5" mesh monofilament nets and evidence indicates this mesh size acted as a gill net for steelhead salmon (Dan Rawding, personal communication). Whether the 4.5" mesh net would similarly act as a gill net for steelhead salmon is unclear. Therefore, achieving the potential indicated with tangle nets will require that we overcome any problems with the tangle net and refine handling techniques to maximize post-release survival of both wild chinook and steelhead salmon.

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APPENDIX A

Study year	Study group	Spring chinook adult catch	Immediate adult mortality	Standard Error	Total tagged and released adults	Jaw tag recoveries (n)	Relative long-term adult mortality (95% conf. int.)	Standard Error	Total mortality due to treatment (95% conf. int.)	Standard Error
2002	Tangle Net (4.5”)	1262	0.5% (6)	0.2%	1218	168	32.4% (26.7-38.7)	6.4%	32.7% (20.0-45.2)	6.3%
	5.5” Net	1900	0.9% (17)	0.2%	1839	215	42.7% (35.5-49.9)	5.1%	43.2% (33.3-53.1)	5.0%
	Controls (Bonn. AFF)	1049	0.0%		1034	211				
2001	Tangle Net (3.5”&4.5”)	536	3.2%(17)	0.8%	512	57	8.8% (0.0-53.0)	13.4%	11.7% (0.0-37.2)	13.0%
	8” Net	836	1.0%(8)	0.3%	812	52	47.5% (42.1-52.9)	8.1%	48.0% (32.3-63.8)	8.0%
	Controls (Bonn. AFF)	1206	0.0%		1196	146				

Appendix B

Geographic area	Location recovered	Control	Tangle	5.5"
I. Below Bonneville Dam	Below Bonneville Dam	1		4
	Bradford Island			1
	Gorge			1
	Gorge Bank 1			4
	Washougal Hatchery	1		
II. Bonneville to McNary	Between Bonne and McNary Dam	3		1
	Bonneville AFF		2	3
	Bonneville Pool	10	15	4
	Bonneville Pool			4
	Carson NFH	10	9	10
	Cascade Locks			1
	Columbia River	2		1
	Deschutes R	5	2	2
	Drano Lake	3	4	6
	Exact location not provided	2		1
	Hood R Trap	1		
	Hood R, OR	1		
	John Day	1		
	John Day		1	
	John Day Pool	1		1
	Kolberg State Park	4		2
	Little White Salmon NFH	18	19	20
	Pelton Dam Trap	6	1	2
	The Dalles Pool	1	2	4
	Threemile Dam	8	11	11
	Umatilla R	1		1
	Umatilla R, below 3 mile dam	3		1
	Warm Springs NFH	5		1
	Wind R	24	10	14
	Zone 6	1		2
III. Upper Columbia above McNary	Entiat NFH	9	4	4
	Icycle Crk	1	2	5
	Klickitat Hatchery		1	1
	Leavenworth	1		
	Leavenworth NFH	24	11	20
	Methow Hatchery	2	1	1
	Ringold Hatchery	2	1	1
	Roza Dam	16	18	30
	Tucannon FH	1	1	1
	Winthrop NFH			1
	Yakima R	1		

Geographic area	Location recovered	Control	Tangle	5.5"
IV. Snake River above Ice Harbor	below Kooskia	1		
	Boise R fish trap	1	2	
	Catherine Crk trib Grand Ronde			1
	Clearcreek			1
	Clearwater R	1		1
	Clearwater R, middle fork	1	1	
	Clearwater R, N Fork	1	1	
	Clearwater R, S Fork		2	2
	Dworshak NFH	8	8	12
	Exact location not provided		1	
	Kooski, ID	1		
	Kooskia NFH		4	7
	Little Goose Dam		1	1
	Little Salmon R	8	6	15
	Little Salmon R fish trap	2	2	2
	Rapid R	1		
	Rapid R Hatchery	5	7	6
	Riggins, ID area 11			1
	Salmon R	3	2	4
	Salmon R fish trap	2	7	1
	Salmon R, South Fork		1	
	Sawtooth FH	3	2	1
	Selway R fish trap	2		
	Snake R	2	2	2

APPENDIX C

A paired ratio estimator was used to calculate the post-release survival, as described below.

Survival Estimator =

$$\frac{\text{\# treatment tagged fish recovered/ \# treatment fish released}}{\text{\# tagged control fish recovered/\# tagged control fish released}}$$

The delta method was used to calculate the variance and obtain the confidence intervals for both the post-release and total mortality, as described below.

If *V*(*X*) implies the variance of the random quantity *X*, then the variance of the post-release mortality is approximated by:

$$\textit{Survival estimator}^2 * V(\textit{immediate survival}) + (\textit{immediate survival})^2 + V(\textit{post-release survival})$$

and the variance of the total mortality is approximated by:

$$\textit{Immediate survival}^2 * V(\textit{post-release survival}) + (\textit{post-release survival})^2 * V(\textit{immediate survival}).$$